A Temperature-Controlled Chamber Based On Vortex Cooling

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1. Abstract

We describe the construction and performance of a temperature-controlled chamber, based on a "vortex" cooler. The chamber is capable of operation between room temperature and -42 °C. The only nontrivial infrastructure requirement is dry compressed gas at 100 psi and 8 cfm.

The chamber is economical, easy to operate and to build using commercially available parts. Since the refrigerant is compressed air, the chamber has minimal environmental impact. It does not generate mechanical vibrations nor electrical noise. It is suitable for testing electronically sensitive and low-power electronics at cold temperatures. We measured the reserve cooling capacity of the cold plate to be 17 watts at -27 °C. At the limiting temperature of -42 °C, reserve cooling power reduces to zero.

2. Vortex Cooling

The vortex cooling tube was invented in Europe around the beginning of WW-II.[1] Compressed air is fed transversely into a hollow tube (figure 1) so that a vortex flow pattern is setup, with a general flow direction towards one end of the tube that also has a conical obstruction. The air flow at the tube's outer radius can escape. The air flow at the tube's inner radius gets reversed, and exits the opposite end.

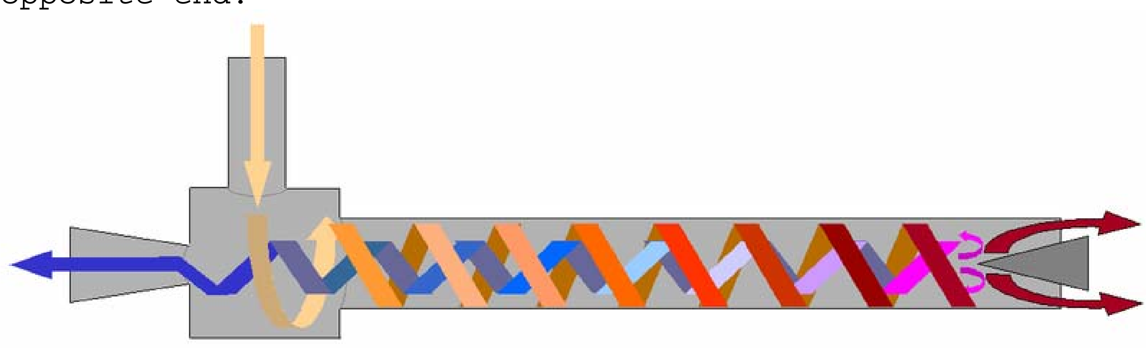

Figure 1: The vortex tube air flow pattern (from Wikipedia, the free encyclopedia 'Vortex tube' http://en.wikipedia.org/wiki/Vortex_tube).

[1] See http://www.visi.com/~darus/hilsch/

The air exiting the (un)obstructed end is (cold) hot relative to the compressed air temperature. The flow rates and temperatures of the hot and cold air masses are controlled by the size of conical obstruction. To date, the vortex cooling phenomenon remains poorly-understood. However, it has found application in the cooling of industrial machines.

3. Setup

The layout is shown in figure 2. The environmental chamber, made of styrofoam, requires a source of *dry* compressed gas at 100 psi and 8 cfm. Moisture in the compressed gas would freeze and may cause obstruction within the gas lines.

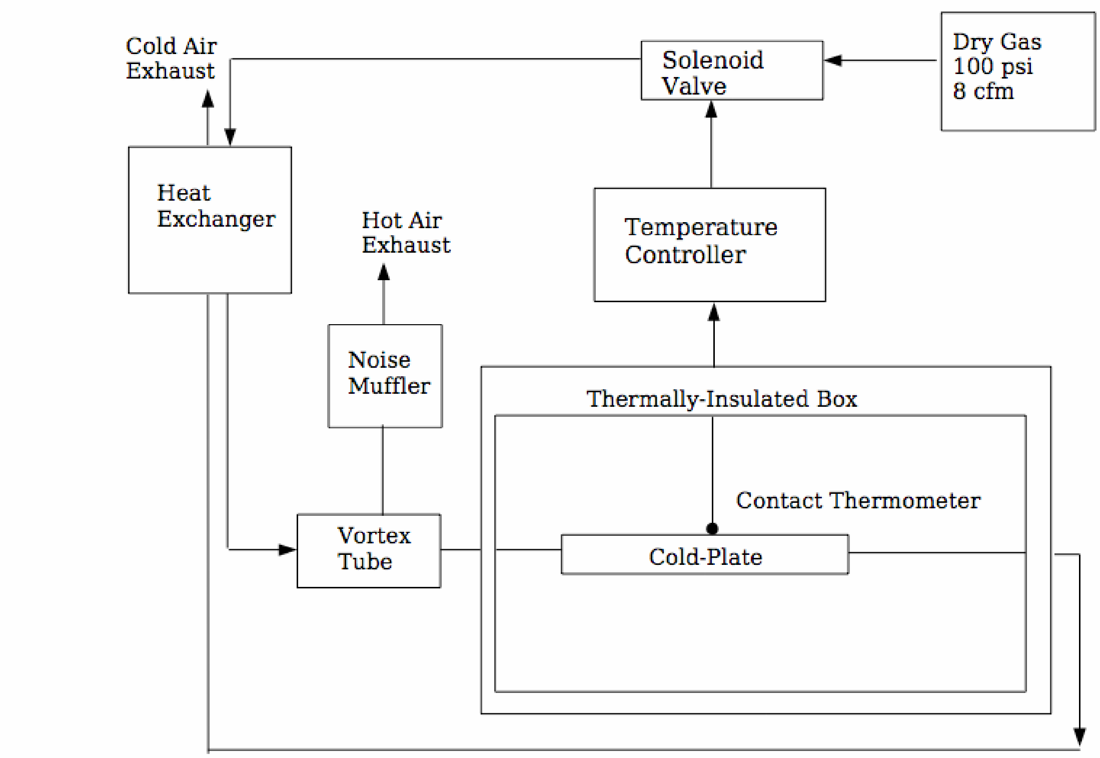

Figure 2: Setup Layout

The dry compressed gas is fed to the vortex cooler[2], which is set up with the 8 cfm generator designed for minimum temperature. The warm air is ejected into a modified cold noise muffler[3], which has the foam core replaced with stainless steel mesh, and then ejected into the room. The cold air is fed into an aluminum cold-plate, which has an internal air channel. The cold air exiting the cold plate is routed

[2] EXAIR Corporation, Model 3908.
[3] EXAIR Corporation, Model 3905.

into a heat exchanger, which cools the incoming compressed gas. This configuration maximizes the available cooling power. A thermometer, attached to a temperature controller, monitors the cold-plate temperature. The temperature controller output drives a solenoid valve, which controls the incoming gas. Figures 3-5 shows more details.

Figure 3

Figure 4: Vortex Cooler and Hot Air Muffler

Figure 5: Cold-plate, Thermometer, and Cold Air Exhaust

4. Result

The vortex cooler can be optimized, via an adjustment screw, for either maximum cooling power, or minimum cold air exhaust temperature. The cold air temperature can be minimized, but with a reduced flow rate (i.e. cooling power). We set the cooler to minimize the temperature. Figure 6 shows equilibrium temperatures as a function of the hot exhaust valve setting. Minimum temperature is achieved at a hot flow valve setting of 0.8 turn from closed.

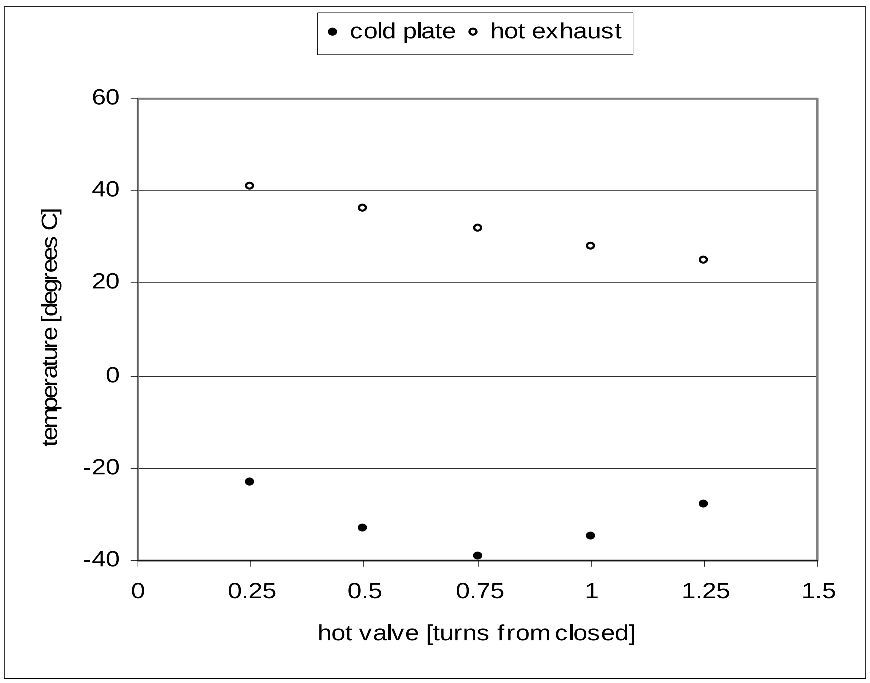

Figure 6: Temperature of hot exhaust and cold plate as a function of the screw adjustment. The cold exhaust air temperature is minimized at 0.8 turn.

Figure 7 shows that the system is able to obtain a minimum temperature of -42 ^{o}C, with no additional thermal load. We estimate a system heat loss of 9 watts from thermal leaks at the minimum temperature, based on the rate of temperature rise of the 900 g aluminum cold plate when cooling is turned off. Figure 8 shows the calculated net cooling capacity available at the cold plate as a function of temperature. Each point is the product of the rate of temperature decrease from Figure 7, the thermal mass and its heat capacity. A 17 watt heater was attached to the cold plate to measure one point.

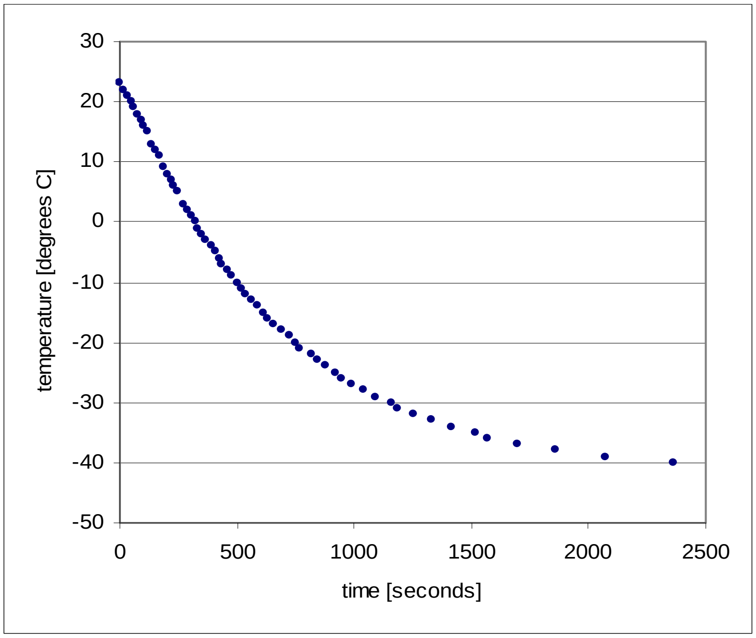

Figure 7: Typical cool down cycle to an ultimate temperature of -42 °C, when ambient temperature is 23 °C.

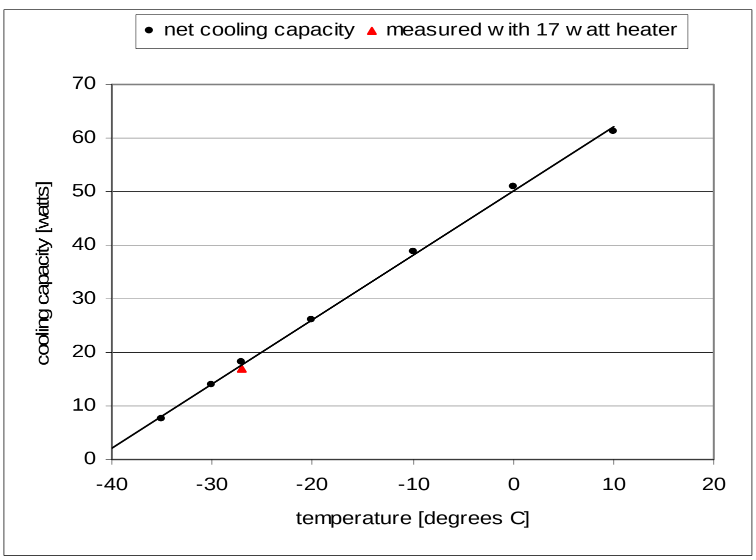

Figure 8: Calculated cooling capacity available at the cold plate as a function of operating temperature. The red data point was measured by placing a 17 watt heater on the cold plate.

Figure 9 shows temperature control of the chamber, using a Watlow 965 on/off controller set to a temperature of -10 °C. The cool-down time can be reduced by using a lighter cold-plate. The oscillations are due to the temperature controller dead-band of approximately 1 °C.

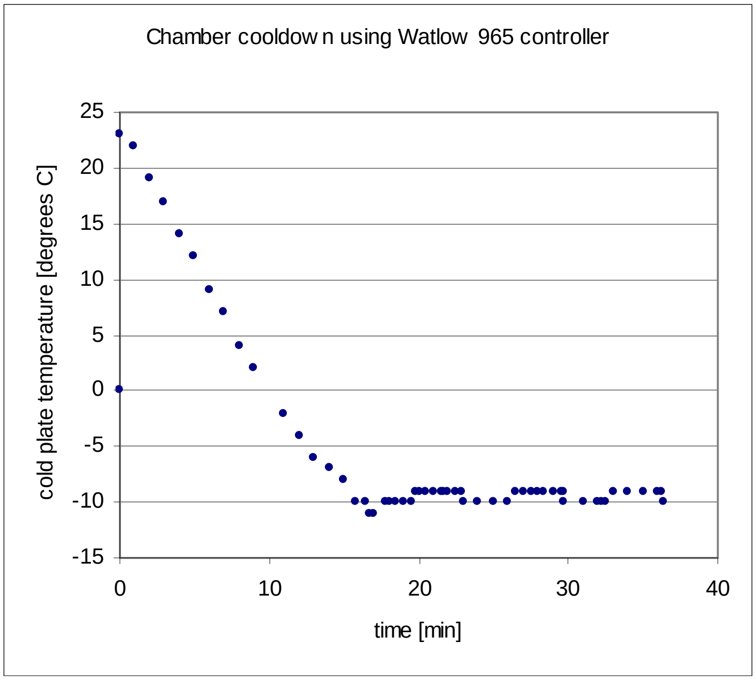

Figure 9: The chamber is cooled initially from room temperature, down to a -10 °C set-point. The oscillations about -10 °C indicate the dead-band of the temperature controller.

Table 1 summarizes the system parameters. Estimated efficiency is based useable power at the cold plate compared to 1750 watts average power consumption of our air compressor operating at a duty cycle required to deliver 8 cfm of air.

Input Dry Gas	100 psi
Input Flow Rate	8 cfm
Minimum Temperature Setting (MTS)	0.8 turns from closed position
Hot Air Flow at MTS	6.6 cfm
Cold Air Flow at MTS	1.5 cfm
Net Cooling Power at -27 °C	17 Watts
Estimated Efficiency at -27 °C	1.0 %

Table 1: Summary of system parameters.

Conclusion

We described the construction and performance of a simple temperature-controlled chamber, based on a vortex cooler. It is suitable for studying low noise and low power electronics. It requires dry compressed gas at 100 psi and 8 cfm. Finally, we note that increasing the input air pressure will increase the cooling performance.